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A collective motion model based on two-layer relationship mechanism for bi-direction pedestrian flow simulation

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ABSTRACT

In crowd dynamic, relations are existed among some pedestrians, which cause frequent interactions during evacuation, creating collective motion phenomena, such as the most common pattern of team-groups. Besides, collective behavior can make a beneficial effect on the evacuation process. Therefore, this paper proposes a collective motion model to simulate bi-direction pedestrian flow. First, a method of group vision sharing is proposed to help pedestrians learn the crowd around. Based on two-layer relationship mechanism proposed, aggregate force and collective collision avoidance force are added into the original social force formula. The aggregate force is the resultant of two forces, one is the attraction among the leader and team members, and the other one is that among members of groups due to the social relations. Simulation results show that the modified model can reproduce the team-groups collective pattern in real world bi-direction pedestrian flow, and can reduce the collision risk with regarding the group as collision avoidance unit. Furthermore, the evacuation efficiency is improved.

1. Introduction

The rapid increases in pedestrians and crowded urban infrastructures have made it a significance to explore the pedestrian flow dynamic. Pedestrian traffic congestion brings great inconvenience to people's travels. Moreover, travel delays result in great losses to the social economy and living quality of residents, especially in the public traffic of airplane and high-speed boarding process, a scientific guidance makes a great help to improve the efficiency [1]. In addition, in several large public places, such as the square in an assembly, crosswalk or subway station during rush hours [2], and a crowded concert scene, safe evacuation is a big issue in emergency cases, such as fire and gas leak. The lack of scientific and effective guidance for personnel evacuation results in chaos, which causes stampede and threaten the safety of the lives and properties of pedestrians. Traditional evacuation drills entail enormous manual labor, material resources, and financial resources, and simulating random events and the subconscious interests of pedestrians for their locations is difficult [3]. Using computer simulation technology for scene modeling, path optimization, and crowd movement behavior modeling to simulate the pedestrian flow in public places can contribute to the design of facilities and emergency evacuation guidance [4].

Pedestrian flow is a typical large crowd movement. In pedestrian flows [5,6], crowd movement includes one and bi-direction, cross, reciprocating, and other forms [7]. The self-organization phenomena of pedestrian flow have distinctive

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features, such as arching and clogging through the bottle neck and stripe formation of intersecting pedestrians in the bi-direction flow [8,9], and some scholars came up with methods to observe the occurrence of phase transition [10]. Therefore, the application of evacuation models to simulate pedestrian flow, especially the most typical one—bi-direction pedestrian flow—has been the focus of many scholars.

In the work of bi-direction pedestrian flow, the relationships among pedestrians which are complex and stable in real life should be taken into consideration. Relationships are usually composed of leading and social relationships, which make pedestrians walk together with a herd mentality and is like some biological cluster phenomena somehow [11–14]. On the basis of the factors above, leading relationship generates team effect and social relations causes small groups effect, these two effects often occur in the process of crowd evacuation. However, most of the existing crowd evacuation simulation models ignore the inter-individual relationships and regard an individual as an isolated particle, which prevent the realistic simulation of crowd evacuation. Thus, a further research on the details of force in team-group effect and in-depth understanding of its behavior and mechanism according to relationship are of vital importance to truly simulating bi-direction pedestrian flow.

This paper proposes a modified social force model (MSFM) that is driven by the two-layer relationship mechanism and a collision avoidance strategy to simulate the self-organized phenomena in bi-direction pedestrian flow. The main contributions of this work are as follows:

(a) A modified social force model is proposed to simulate the self-organized phenomena of bi-direction pedestrian flow.
(b) The combination of leading and social relationships forms the two-layer relationship mechanism.
(c) A method of group vision sharing is proposed to help pedestrians learn other pedestrians around.
(d) An aggregate force, including visual impact factor is added to the original formula, and the clustering method is introduced.
(e) The collision in bi-direction pedestrian flow during intersection is reduced by a collective collision avoidance strategy which regards the group as an avoidance unit.

Based on the contributions above, the collective pattern of team-group is reproduced. Each group moves toward the target through the guidance of a leader. Meanwhile, team members gather into small groups according to their social relation. In addition, the lane formation of bi-direction pedestrian flow is reproduced under the collective collision avoidance strategy. A rich set of environmental attributes, specifically a real path environment, is considered. Thus, similar scenes are built to simulate the real scenes. The remainder of this paper is organized as follows. Section 2 mainly introduces related works on pedestrian flow simulation and social force model. Section 3 discusses the original social force model (OSFM). Section 4 presents the MSFM for bi-direction pedestrian flow simulation. Section 5 elaborates the model framework and implementation process. Section 6 shows the efficiency of the proposed model by experimenting on the effects of relationship density and relationship aggregation on the different density flows, and the validity of the model is verified by numerical comparison. The simulation results show that the MSFM can make the pedestrians in a team march with a leader and gather together in small groups to interact with each other, which can achieve orderly and efficient evacuation. The conclusion and future research focus are presented in Section 7.

2. Related work

In the last decade, numerous simulation models, classified into two categories of microscopic and macroscopic [15], have been presented to elucidate the underlying dynamics of bi-direction pedestrian flow behaviors. Jiang et al. proposed a high-order macroscopic model, which shows that the traffic sonic speed and the group size influence on the width and number of lines [16]. However, macroscopic models cannot commendably describe the local details of pedestrian behavior. Generally, microscopic models mainly include the social force model (SFM) [17–19], lattice gas model (LGM) [20–23], and cellular automaton model (CAM) [24–27]. Using a microscopic pedestrian model, Guo et al. investigated the effects of the walkway corner and pedestrian preference to inside routes on pedestrian queue, trajectory, and flow-density relation [28]. From the individual's perspective, the focus of microscopic models on the interaction between the individual and the environment can compensate for the deficiencies of the macroscopic ones to a certain extent. The three models above have been commonly used to simulate pedestrian flow.

Based on CAM, Wang et al. came up with some rules for double-pedestrian teaming, which showed that team movement contributes to the significant corridor capacity effects and the type of teaming behavior influences the effects significantly [29]. Wei et al. proposed a novel pedestrian model that uses direction and collision gains to calculate the target position and extend the three-dimensional spaces of stairs [30]. Nowak and Schadschneider introduced an order parameter to analyze quantitatively four different states, i.e., free flow, disordered flow, lane formation, and gridlock [31]. Xue et al. introduced a concept of a dominant row, and quantify the evolution process of the lane formation to show steady separate lanes can form even in dense conditions [32]. Weng et al. simulated pedestrians counterflow with different walk velocities, and observed phase transition among freely moving phase, lane formation phase, and perfectly stopped phase with the range of entrance densities [33]. Tang proposed a model to investigate the effect of elementary students' individual properties on the evacuation process [34]. Burstedde et al. proposed a 2-dimensional cellular automaton model shown the introduction of such a floor field is sufficient to model collective effects and self-organization encountered in pedestrian dynamics [35].